Fish Assemblages: The Influence of Habitat and Hydrology

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Fish Assemblages: The Influence of Habitat and Hydrology

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Abstract

Rivers and streams are irreplaceable resources for both human consumption and recreation. Disturbances of these ecosystems can lead to degradation of part, or all, of the stream system. Alteration of habitat influences and changes the fauna within that environment. We sampled agricultural, headwater intermittent and perennial streams in the White River watershed in Delaware County in East-Central Indiana. We sampled 16 sites in May of 2007 using backpack electrofishing. Fish were identified and we assessed the response of fish assemblages and identified relationships in fish abundance and diversity with stream habitat and hydrology. We hypothesized tolerant fish species and lower species richness would characterize both agricultural and intermittent streams. We tested for a relationship and interactions among fish assemblages with habitat and hydrological variables.

Introduction

Clean water is a vital human amenity as freshwaters are frequently used as drinking water sources and for recreational venue (Carpenter et al. 1998). Streams are fundamental components of these resources. They compose over two-thirds of total available freshwater (Freeman et al. 2007) and can exhibit high species diversity and productivity. Human disturbances of these ecosystems can lead to poor water quality (i.e., decreased diversity and aesthetic value) and decrease the utility of these assets for humans (Carpenter et al. 1998).

Disruption of surrounding landscapes of a stream directly affects water quality and stream habitat and indirectly affects organism biodiversity (Lammert and Allan 1999, Allan 2004, Harding et al. 1998). Land-use practices frequently influence stream habitat and hydrology (Poff 1997, Harding et. al 1998, Lammert and Allan 1999, Scott and Hall 1997, Stewart et. al 2001, Allan 2004, Carpenter et al. 1998). Agricultural activities can yield broad alterations in landscapes through tile drainage and channel modifications (Allan 1995, Carpenter et al. 1998, Quinn et al. 1997) that cause diffuse nutrient and sediment pollution (Lammert and Allan 1999, Carpenter et al. 1998, Stewart et al. 2001, Plantinga 1996). Cascading events may further alter stream habitat through decreased stabilization of the existing channel. These habitat changes in response to agricultural activities may alter fish communities. For example, Harding et al. (1998) documented that fish in agricultural streams that occupy the streambed were replaced by more tolerant species that use the water column. Marchetti and Moyle (2001) also identified numerous effects of agricultural activity on streams caused by altered flow regimes including changes in channel structure, sediment transport, species diversity, and community composition. Alterations affect the aquatic biota (Osmundson et al. 2002)and these changes alter the natural flow regime which is critical for fish assemblage structure. Fish assemblages are robust indicators of water quality because they react and change in abundance or occupancy with the surrounding environment (Scott and Hall 1997).

Intermittent stream community compositions vary greatly due to physio-chemical variation caused by decreased flow conditions (Closs and Lake 1994) and this dependence on chemical conditions is amplified by agricultural inputs. Closs and Lake (1994) defined intermittent streams as streams that cease to flow on a regular and predictable basis. Fish become concentrated in pools when flow decreases and water recedes in association with intermittent flow (Capone and Kushlan 1991, Labbe and Fausch 2000). As pool depth, pool persistence, and channel size increase in intermittent streams, species richness increases (Capone and Kushlan 1991). In contrast, perennial streams have constant and predictable flow patterns and biota abundance and richness increase with permanent flow (Closs and Lake 1994). Flow consistency is a determining factor in severity of physio-chemical alterations, and agricultural runoff is likely less concentrated and carried downstream rather than becoming concentrated in stream pools when flow is more permanent as in perennial streams.

We studied headwater streams in an East-Central Indiana watershed dominated by agriculture to assess the response of fish assemblage abundance and diversity patterns with stream habitat and hydrology. We hypothesized tolerant fish species and lower species richness would characterize both agricultural and intermittent streams. We predicted differences between row crop and pasture agriculture sub-watersheds based on differences in water chemistry and physical habitat, and differences among perennial and intermittent streams due to flow variation. We tested for a relationship for fish assemblages with habitat and hydrological variables.

Study Sites

We sampled 15 agricultural headwater streams located in the Buck Creek watershed, a tributary of the East Fork White River, within Delaware and Henry counties in east central Indiana (Figure 2) in May of 2006. Streams were < 2 m wide, classified as either intermittent or perennial, and as row crop agriculture or pasture. We found high variation among sites for physical and chemical variables (Table 1).

Methods

Sites were selected based on flow (intermittent or perennial) and agriculture (pasture or row-crop, Figure 1). All sites were headwater (first/second order) streams. We quantified water quality at each site as pH, dissolved oxygen, conductivity, and temperature using a portable Hydrolab. A Headwater Habitat Evaluation Index (HHEI) score was created for each site. This index summarizes habitat characteristics of substrate, maximum pool depth, bank full width, riparian zone and floodplain quality, flow regime, sinuosity, and stream gradient. Flow was calculated at three locations on each stream using a Marsh-Mcbirney flowmeter, with three replicates for each segment for a total of nine flow values. We used mean flow in our analyses. Distance from Buck Creek was quantified using Google Earth online software to quantify stream distance from each site to its convergence with Buck Creek.

Fish were collected in 100-m reaches using single-pass electro-fishing once in early spring with two netters. Most fish were identified in the field, except for questionable individuals that were preserved in 70% alcohol and later identified in the laboratory.

Data Analysis

We used Canonical Correspondence Analysis (CCA (PC-ORD, McCune and Mefford 1999) to examine fish and habitat relationships. CCA is a direct gradient analysis that assesses the strength of the environmental variables relationships to species composition. The CCA options we used were, row and column scores standardized by centering and normalizing, ordination scores scaled to optimize rows, site scores linear combinations of variables, and a Monte Carlo test of significance with 100 randomizations tested for significant differences from a randomization. Two sample t-tests were run to test for differences in agriculture and flow type. Species richness was calculated for all sites (Figure 3). Shannon- Weiner index of diversity was calculated for each site based on agriculture type (Figure 4) and flow pattern (Figure 5).

Results

We captured 13 species during electro-fishing. The most abundant were mottled sculpin, creek chub, and blacknose dace (Table 2). Species richness ranged from 0 - 9 species per site with a mean of four. The mean site depth was 0.2 m, mean flow was 0.3 ft/s, and mean site distance from Buck Creek was 1,300 m.

Ordination

Three Canonical Correspondence Analysis axes explained a total of 53.3% of total variation in species abundances among sites (28.8, 12.8, and 11.7%, respectively). All axes were significantly different from randomly generated axes in Monte Carlo analyses ($P < 0.05$). Environmental gradients driving the first axis include HHEI score and site distance from Buck Creek, whereas gradients in agriculture type and site distance from Buck Creek were strong on the second and third axes (Figures 6 and 7). Axis 1 was primarily driven by HHEI scores and distance of the site from Buck Creek.

Brook stickleback, blackside darter, green sunfish, and brook lamprey were in higher abundance at sites further distant from Buck Creek (Figure 6). Mottled sculpin and blacknose dace occurred at sites with higher HHEI scores (Figure 6). The second CCA axis was based primarily on site distance and agriculture type, either row crop or pasture. Stoneroller and White Sucker had highest abundances at pasture sites and orangethroat darter occurred at row crop sites. CCA Axis 3 was an axis of site distance and agriculture type (row crop/ pasture). Bluegill and green sunfish occurred in higher abundance at pasture sites. Stoneroller, Brook stickleback, and orangethroat darter occurred at highest abundances at sites farther from Buck Creek (Figure 7).

Discussion

The results of this study suggest support previous theories that agricultural activities alter the biological and habitat integrity of streams (Allan et al. 1997). Agricultural sites had lower fish diversity than expected. Similar results were obtained in the study by Townsend et al. (1997) of land use effects on aquatic vegetative morphology and macroinvertebrate communities in which they found pasture streams had low representation of endemic plant species. Human land-use activities frequently have negative impacts on water quality and aquatic biota (Freeman et al. 2007).

We found slight differences in fish abundance and distribution in relation to pasture or row-crop agriculture from the ordination; however t-tests did not support these findings. Although the Stoneroller and White Sucker had highest abundances at pasture sites and orangethroat darter occurred at row crop sites (Figure 6), results do not support a significant relationship. The two site types were scattered in the CCA ordinations with no distinct pattern. We predicted differences in species composition and abundance based on agricultural practices that have different effects on in-stream habitat. We did not find significant differences between agriculture types, our results may be due to site locations as they are close in proximity. Also, if both agriculture practices severely impacted the streams then biodiversity would be decreased throughout the sites, which is true for these streams. For example, if sediment loading and turbidity were unusually high, this would limit the amount and types of species that could survive there. This explains the very low species abundances and diversity.

Our prediction of differences between row crop and pasture agriculture practices, and intermittent and perennial streams were not supported by the data. This is also likely due to low species diversity and abundances at all sites. By increasing the number of sites and sampling longer stream reaches, we would be able to more fully understand and interpret the similarities and differences among these land-use and flow gradients.

Conclusion

HHEI score, agriculture type, and site distance provided strong explanation of the species abundance patterns in the CCA analysis. Human alterations from agriculture affect riparian zone quality, hydrological variables (e.g., depth), and substrate. These alterations affect species abundance and diversity, which were low across these sites. The habitat evaluation score (HHEI) quantifies these variables and provided a significant explanation of variation in species composition suggesting a relationship among these variables and fishes. Agriculture type was also a primary driver, and our ordination results suggested a difference in species composition between row crop and pasture agricultural streams, however t-test results were not significant. Site distance from Buck Creek was a strong explanatory variable for all axes and species composition at our sites. Streams adjacent to Buck Creek tended to be larger and had higher flow, and streams further distant tended to be smaller and shallow with decreased flow.

The Buck Creek watershed has a low elevation gradient. Sites are homogenous in elevation and it is not considered an imperative factor. The variation in fish communities then could be due to the differences in stream size, point/non-point pollution, surrounding land use, channel modification, or in-stream blockage such as dams or large sediment deposits. We conclude that these agriculturally impacted headwater stream fish assemblages are simple and structured by stream habitat and quality. From a management perspective, in order to have successful fisheries we recommend a program to monitor stream and water quality.

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Table 1: Ranges of stream variables.

Variable	Range
Depth (m)	0-0.251
Distance (m)	79-3240
Temperature °C	10.45-17.61
Species richness	0-9
Conductivity	311-752
Dissolved oxygen (mg/l)	6.65-16.85
pH	7.58-8.51
Flow (ft/sec)	0-0.97
HHEI score	49-76
Abundant Substrate	Silt

Table 2: Species abundances.

Species	Total # Individ.
Mottled Sculpin	309
Creek Chub	138
Blacknose Dace	114
Orangethroat Darter	60
Green Sunfish	45
Central Stoneroller	36
Bluegill	30
Brook Stickleback	19
White Sucker	19
Brook Lamprey	3
Blackside Darter	3
Common carp	2
Largemouth bass	1

Figure 1: Site in cow pasture.

Figure 2: Location of study sites.

Figure 3: Species richness per site.

Figure 4: Shannon-Weiner diversity by site. Green bars indicate pasture sites and black bars indicate row crop agriculture.

Figure 5: Shannon-Weiner diversity by site. Blue indicates an intermittent stream, black indicates a perennial stream.

Figure 6: First and second axis from CCA analysis. Arrow lengths represent the strength of environmental variables with the canonical axes. Red squares are fishes and black circles are sites.

Figure 7: Canonical Correspondence Analysis. Axes 1 and 3. Axis 3 is primarily driven by site distance from Buck Creek and agriculture type (Row Crop/ Pasture).

Figure 1:

Figure 2:

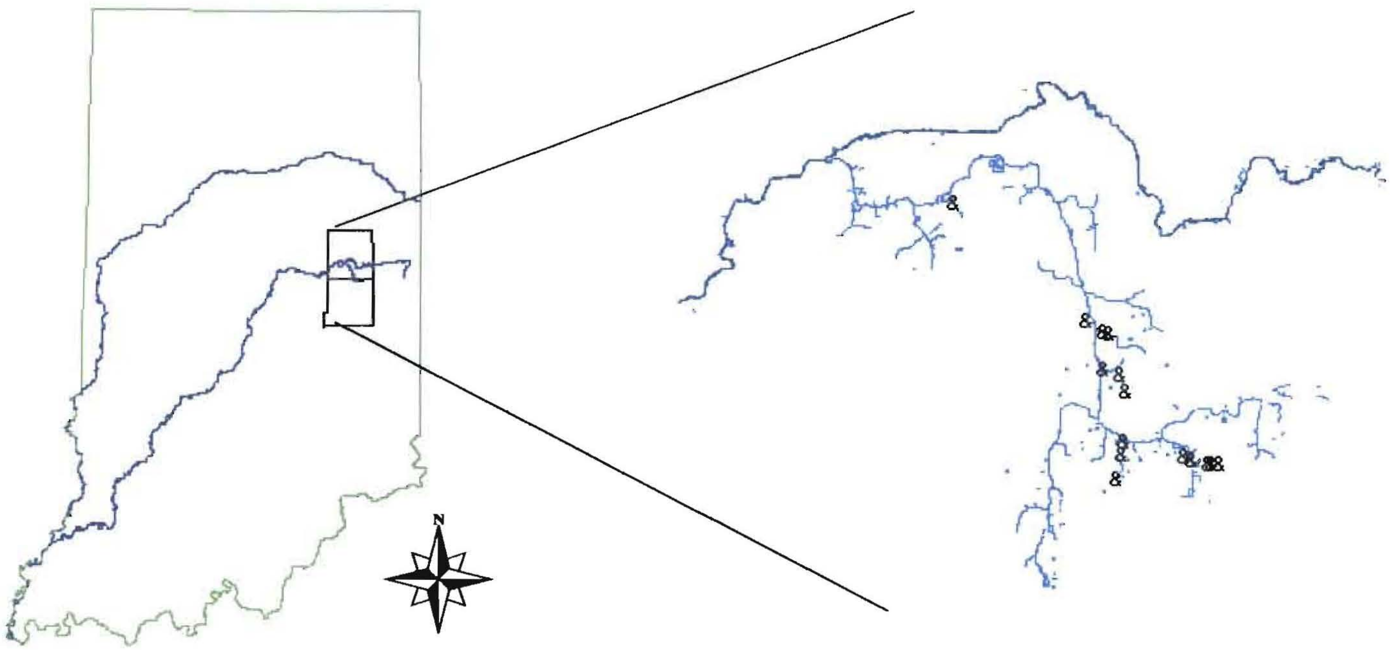


Figure 3:

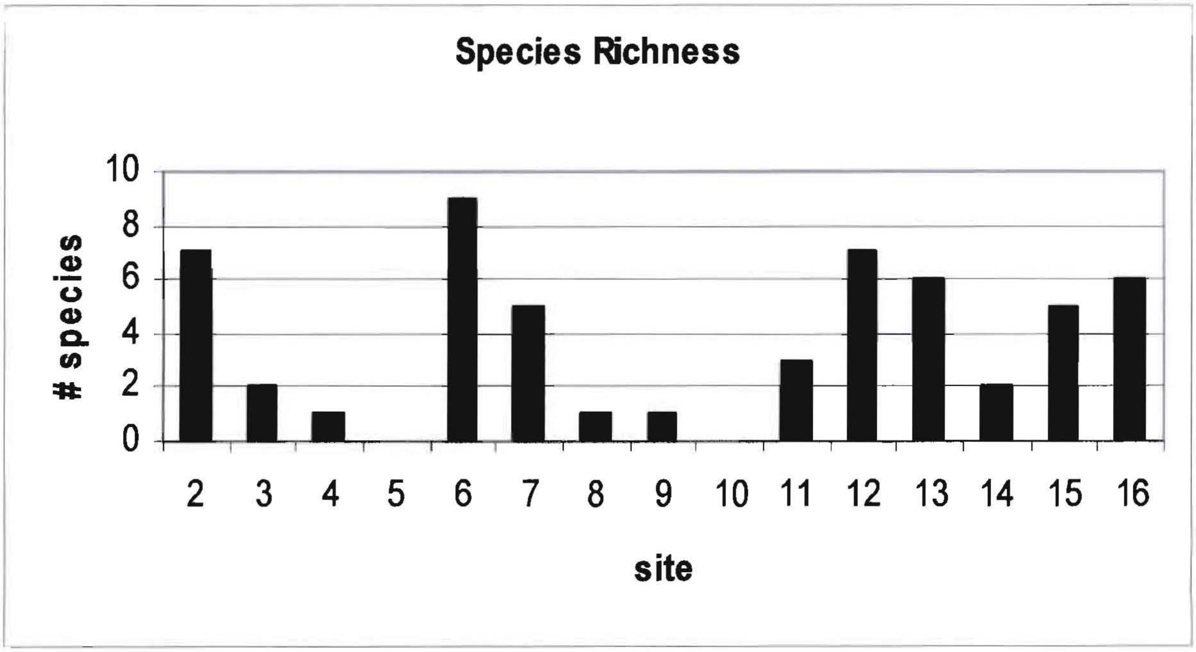

Species Richness
species
10
8
6
4
2
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
site

Figure 4:

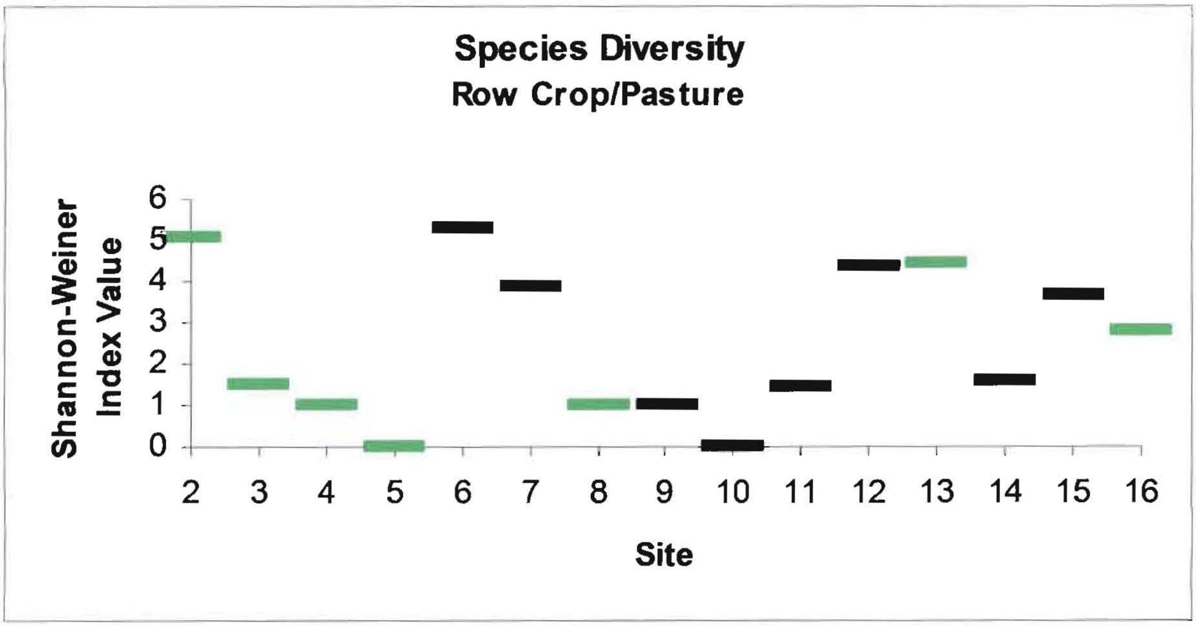
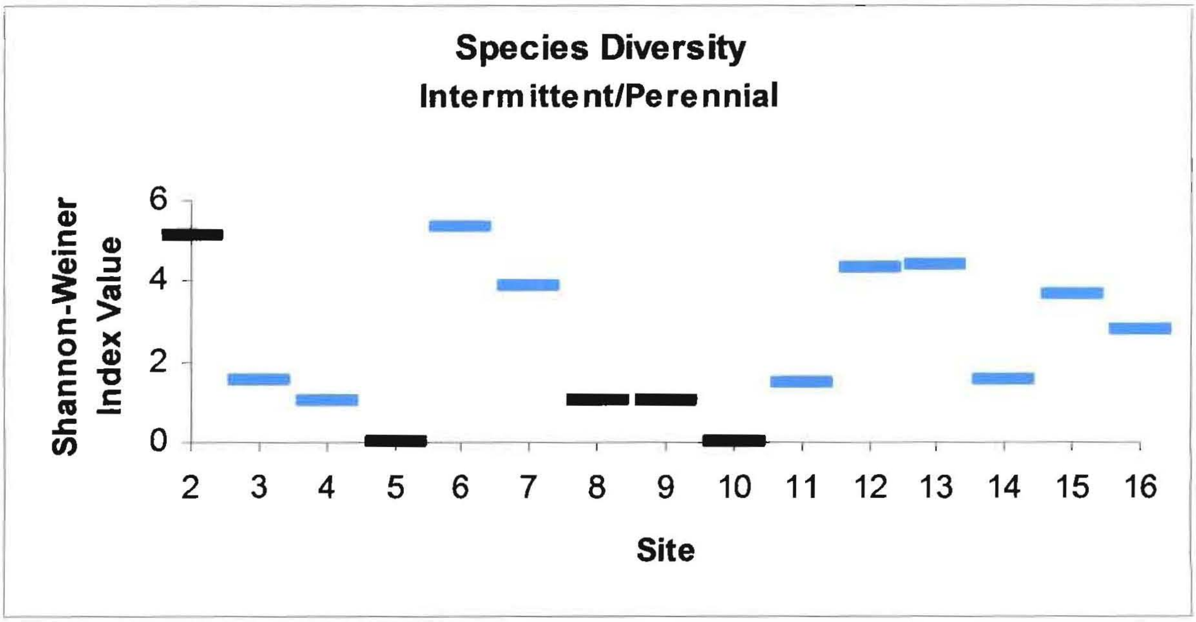

Species Diversity
Row Crop/Pasture
Shannon-Weiner Index Value
0
1
2
3
4
5
6
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Site

Figure 5:


Species Diversity
Intermittent/Perennial
Shannon-Weiner Index Value
6
4
2
0
2
3
4
5
6
7
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10
11
12
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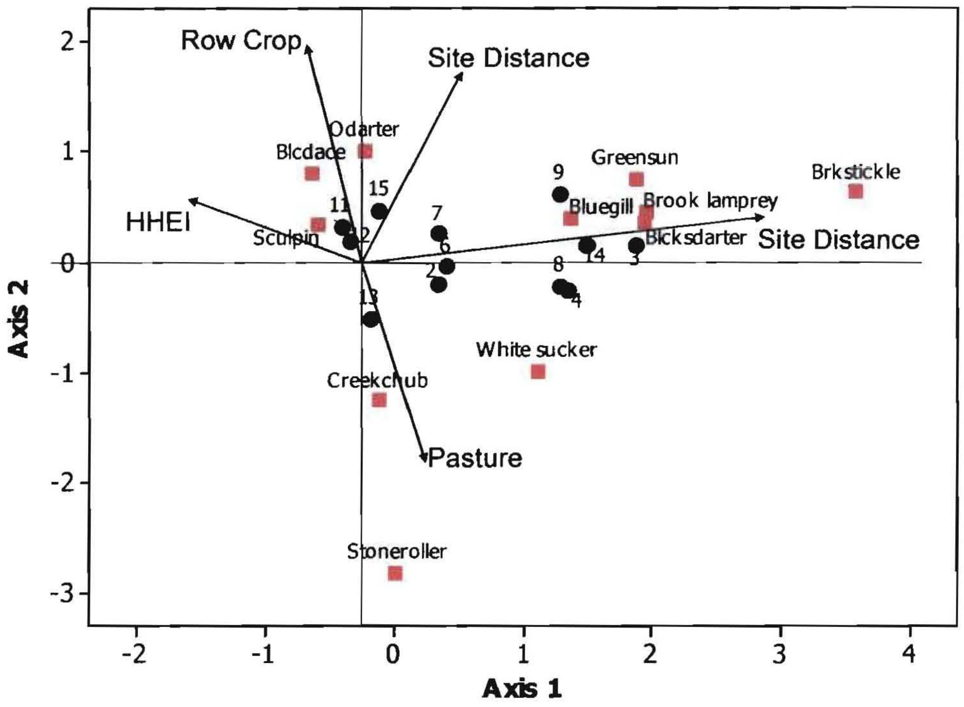
14
15
16
Site

Figure 6:


Row Crop
Site Distance
Odarter
Blcdace
Greensun
Brkstickle
HHEI
Bluegill
Brook lamprey
Sculpin
Blcksdarter
Site Distance
White sucker
Creekchub
Pasture
Stoneroller
Axis 2
Axis 1
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1
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-1
-2
-3
-2
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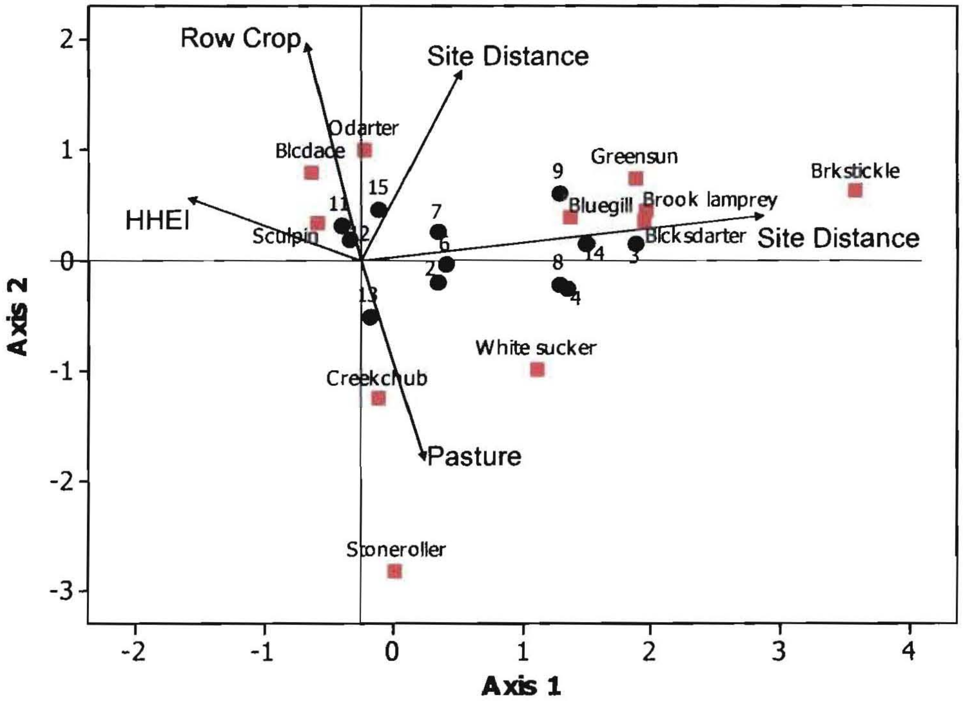
Figure 7:


Row Crop
Site Distance
Odarter
Blcdace
Greensun
Brkstickle
HHEI
Bluegill
Brook lamprey
Sculpin
Blcksdarter
Site Distance
White sucker
Creekchub
Pasture
Stoneroller
Axis 2
Axis 1
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